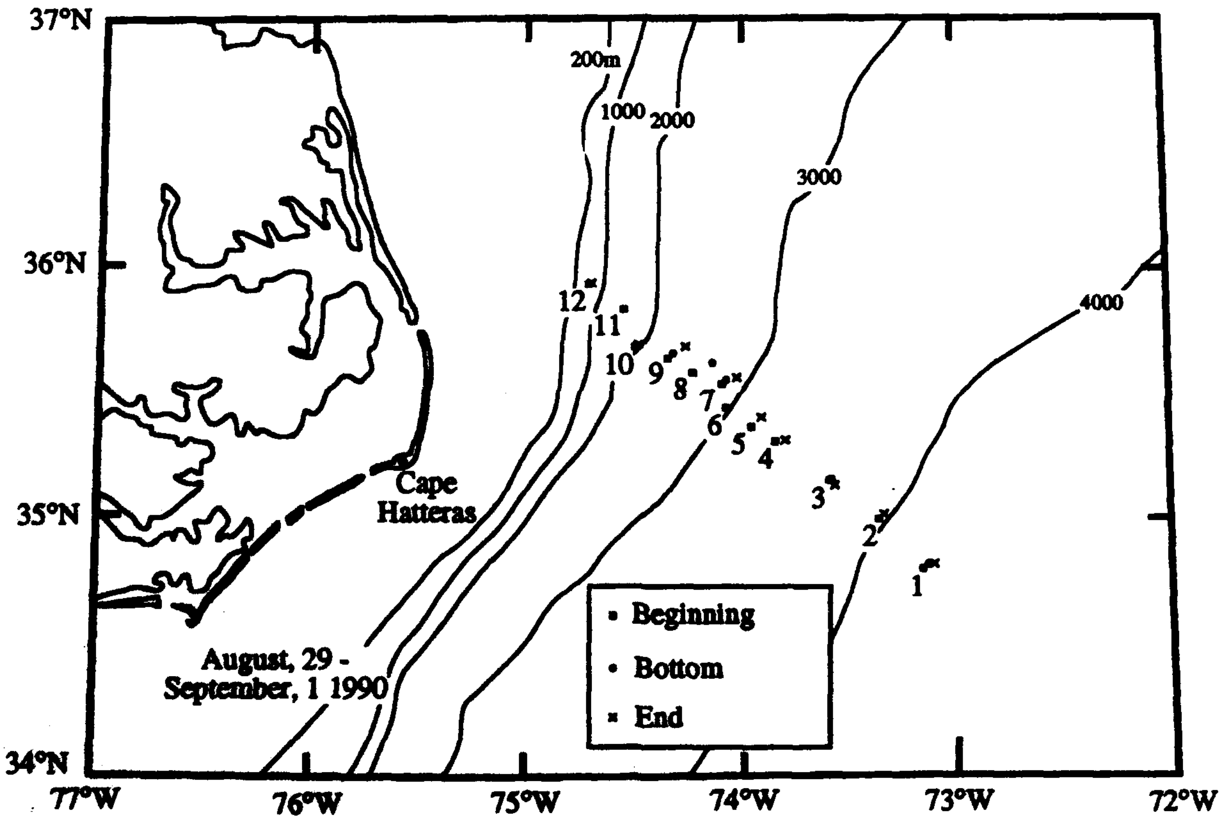
SYNOPTIC OCEAN PREDICTION EXPERIMENT

EN216 CTD SECTION DATA REPORT



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University of North Carolina at Chapel Hill

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SYNOPTIC OCEAN PREDICTION EXPERIMENT

(SYNOP)

EN216 CTD SECTION DATA REPORT

R/V ENDEAVOR CRUISE EN216
AUGUST 29 - SEPTEMBER 1, 1990

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Abstract

A CTD section was taken across the Gulf Stream during late August, 1990, approximately 100 km downstream from Cape Hatteras. The work was done from the *R/V Endeavor* during the third leg of cruise EN216, which was part of the SYNoptic Ocean Prediction (SYNOP) program. The section consisted of 12 stations located along a line from 34°50'N, 73°10'W to 35°57.23'N, 74°43.14'W, spaced 8 to 30 km apart. The Seabird Sealogger utilized was equipped with conductivity, temperature, pressure, and oxygen sensors. Nominal drop speed was 0.5 - 1.0 m/s, with a sampling rate of 1 Hz. This report discusses the acquisition and processing of the CTD data obtained along this section. In addition, plots of potential temperature *vs.* salinity, salinity *vs.* pressure, potential temperature *vs.* pressure, and oxygen *vs.* pressure are shown for each station. Vertical sections of salinity, potential temperature, density, and oxygen are also presented.

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I INTRODUCTION

A CTD section was taken across the Gulf Stream during late August, 1990 approximately 100 km downstream from Cape Hatteras (Figure 1). The work was done from the *R/V Endeavor* during the third leg of cruise EN216, which was part of the Synoptic Ocean Prediction (SYNOP) program. The acquisition and processing of the CTD section data are discussed below, and the data are presented in profiles and sections. A complete report of the cruise can be found in Cronin (1990).

II SECTION INFORMATION

The section taken on EN216 consisted of 12 CTD stations occupied during the period August 29 through September 1, 1990. The first station was located at 34°50'N, 73°10'W. Subsequent stations were spaced 8 to 30 km apart along a line that ran shoreward in a northwesterly direction, ending at station 12 (35°57.23'N, 74°43.14'W). Table 1 lists the locations at the start of each cast, at the end of each downcast, and at the end of each subsequent upcast (see also Figure 1). Table 2 lists the station bottom depths, distances between stations, and the distance drifted during casts.

A Seabird Sealogger CTD was utilized, sampling at 1 Hz, with a nominal drop speed of 0.5 - 1.0 m/s. This Sealogger was equipped with conductivity (C), temperature (T), pressure (P), and oxygen (O) sensors, horizontally plumbed with pump, and mounted beneath a rosette of water sample bottles. Eight bottles were tripped on every upcast, two at each of four depths, chosen on the basis of T data being sent up the wire. The target stop temperatures were 2.50, 3.65, 4.65, and 18.65 °C at the offshore stations 1-8, and 3.60, 4.60, 6.05, and 12.00 °C at the shoreward stations 9-12. Salinity data from these water samples were used to calibrate the conductivity data (described below).

Additional data were obtained along the section from (1) POGO casts performed at each station as the CTD neared completion of its upcast, and (2) a ship mounted ADCP that recorded along the ship track between stations. These data are not discussed here.

III DATA PROCESSING

Processing of the CTD data fell into three discrete steps. These were (1) adjustment of temperature, pressure, and conductivity for instrument drift, based on calibration data, (2) despiking of the salinity records by alignment in time and filtering of the C, T, and P records used to compute S, and (3) the removal of "junk" from the records. "Junk" includes data from above the water surface, data taken during bottom loiter or during pauses in the cast for bottle samples, and data from periods of ship heave.

The adjustment of temperature data was based on instrument calibration data taken before (7/20/90) and after (1/16/91) the EN216 cruise. These data indicate an instrument drift of +0.0054 °C/6 months (average over T from 1.0 to 31.0 °C). Assuming a linear drift with time, 1/6th of this drift would have occurred by the cruise date. Thus the T data were adjusted according to

$$T_{adj} = T_{raw} - 0.0009\ ^{\circ}\mathrm{C}.$$

Adjustment of pressure data proceeded similarly. Calibration data taken before (8/9/90) and after (1/11/91) the cruise indicated a sensor drift that was a function of P (Figure 2). Assuming a linear drift in time, 1/10th of this drift would have occurred by cruise time, so the pressure data were adjusted according to

$$P_{adj} = P_{raw} + P_{delta}$$

where

$$P_{delta} = a_3 + a_2 \times P_{raw} + a_1 \times P_{raw}^2,$$
$$a_1 = 2.803 \times 10^{-8},$$
$$a_2 = -5.212 \times 10^{-4},$$
$$a_3 = 4.169 \times 10^{-1}.$$

This adjustment turned out to be quite small in comparison to the scatter observed in the calibration data. That is, the error generated by using the best-fit polynomial derived from the calibration data (known pressures applied, instrument output read, polynomial fit to the relation) to compute the pressure from the calibration instrument output is of the same order as the drift correction applied.

Adjustment of the conductivity data was more complex. Salinity data from the water samples taken during the CTD casts were used to adjust the CTD conductivity data. First, the average Salinity "measured" by the CTD was calculated from average values of C, T_{adj}, and P_{adj} during each bottle stop, using the SAL78 algorithm found in Fofonoff and Millard (1983). This S will be referred to as S_{calc}. S_{calc} at each bottle sample stop was then compared to the two bottle samples from that stop (Table 3). The differences were used to calculate a correction as a function of S_{calc} (Figure 3). The S_{calc} values were then corrected according to

$$S_{adj} = S_{calc} - S_{delta}$$

where

$$S_{delta} = b_2 + b_1 \times S_{calc},$$
$$b_1 = 3.322 \times 10^{-3},$$
$$b_2 = -1.154 \times 10^{-1}.$$

Then the corresponding C_{adj} was calculated from S_{adj}, P_{adj}, and T_{adj} using the iterative technique described in Fofonoff and Millard (1983).

Once the data had been adjusted for instrument drift, spikes in S were removed. Spiking is a consequence of calculating S with C and T values from different water parcels. This results in an S value that does not represent the S in either parcel. This mismatch between C and T values occurs due to two factors. First, the C and T sensors are separated in space, so that the C and T recorded at any one time are from two different parcels of water (albeit closely situated ones). If these properties vary rapidly in the vertical, the resulting mismatch can be large enough to cause spiking. This problem can be minimized by "aligning" the data. This involves shifting either T or C in time so that the values used to calculate S at any one time are from the same parcel of water. The amount of shifting required is found by trial and error - shifting the data, calculating S and density [calculated from S, T, and P using the algorithm of Fofonoff and Millard (1983)], and seeking the shift that minimizes spiking and density inversions. The second contributor to the C - T mismatch is a discrepancy in instrument response time. The C sensor response time is much faster than that for T (see Seabird literature for details). Suppose the CTD encounters a location in the vertical where C and T change abruptly. As the C sensor encounters the C step, it registers it almost immediately, while the T sensor records the T step as something resembling an exponential adjustment. The calculation of S using T values from this adjustment period will lead to incorrect S values (spiking). The ideal solution to this problem would be to lower the T sensor response time. Since this certainly cannot be done after the measurements have been taken, the alternative is to effectively "slow down" the C sensor response. This can be accomplished by smoothing the C data with a simple narrow filter. The type and width of filter required is found by trial and error - filtering, calculating S and density, and seeking a minimum amount of spiking and density inversion.

The downcast salinity data from the EN216 CTD casts did indeed show evidence of spiking. The C sensor encountered all water parcels before the T sensor, so shifting the C values forward (dropping the first few values) improved the S data. Trials with subsets of data indicated that a forward shift in C of two records, followed by filtering C,T, and P with a five-weight triangular filter was optimum.

Upcasts showed little evidence of spiking, so no alignment or filtering procedures were applied. The smooth records were presumably a consequence of instrument configuration. The CTD was mounted under a bottle sample rosette, so was in the wake of the rosette on the upcasts. The steps in C and T that were encountered, and caused the spiking on the downcasts, were apparently destroyed by the rosette on the upcast before the CTD could sample them. (The slow rate of sampling - 1 Hz - would have made microscale measurements of the turbulence in the wake unlikely.)

Finally the records were cleaned by removing measurements made above the water surface, during bottom loiter, and during pauses for bottle samples on the upcasts. This was done by inspection of the P data. Data from periods of ship heave were also removed. Evidence for ship heave was decreasing P during a downcast or increasing P during an upcast. Such periods were processed so that the P values were monotonically increasing (decreasing) on downcasts (upcasts). Segments in the C, S, T, and O data corresponding to the deleted P sections were then removed.

The Oxygen records were not processed extensively. The periods of top and bottom loiter, bottle stops, and ship heave were excised, but no other processing was attempted. Therefore some quality assessment of the data may be required before it is used.

IV DATA PLOTS

Data plots fall into three main types: (1) potential temperature (θ) vs. salinity plots, (2) data profiles, and (3) vertical sections. The form of these plots loosely follows those of Pickart *et al.* (1992) for comparative purposes. Potential temperature vs. salinity curves for the upper water column ($\theta > 8.0\ ^{o}C$) and the lower water column ($\theta < 8.0\ ^{o}C$) are shown in Figures 4 and 5, for stations 12 through 1 (in onshore to offshore order). Figures 6, 7, and 8 show profiles of salinity, potential temperature, and oxygen. The data in Figures 3 through 7 were processed as described in section III. Figures 9 and 10 show vertical sections of salinity, potential temperature, density (in sigma units), and oxygen. The density plot is a composite of σ_0, $\sigma_{1.5}$, and $\sigma_{3.0}$. These are densities calculated from (1) salinity, (2) potential temperature referenced to pressure surfaces P = 0, 1500, and 3000 dbar, respectively, and (3) pressure = 0, 1500, and 3000 dbar. The section orientations are onshore to offshore, left to right; the horizontal axis is distance from station 12. To plot these sections, the processed data were oversampled to uniform 0.1 m increments, filtered with a 100 m low-pass filter, and subsampled to 50 m increments in depth. Then the data were linearly interpolated onto a regular grid with 50 m spacing in the vertical and 10 km spacing in the horizontal. Actual station locations are indicated along the top of the vertical sections. The bottom topography values were found by adding the maximum CTD depth from each cast to the "height above bottom" values recorded in the cruise log. Since the height above bottom information was not available for station 2, an average from the other stations was used.

V ACKNOWLEDGEMENTS

The data were gathered under the direction of D. Randolph Watts of University of Rhode Island (URI). We thank him and the scientific crew on board cruise EN216, third leg. Thanks also to the Captain and crew of the *R/V Endeavor*. Bottle sample salinities were determined at URI. This work was sponsored by the National Science Foundation, grants OCE87-17141 and OCE87-17144, and by the Office of Naval Research, grants N00014-90-J-1596, N00014-90-J-1568, and N00014-90-J-1548.

VI REFERENCES

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Fofonoff, N.P. and R.C. Millard, Jr., 1983. *Algorithms for computation of fundamental properties of seawater, UNESCO technical papers in marine science, #44*, 53 pp.

Pickart, R.S., T.K. McKee, and W.M. Smethie, Jr., 1992. *Hydrographic Data from Endeavor 214: A Study of the Gulf Stream - Deep Western Boundary Current Crossover, WHOI-92-23*, 118 pp.

Table 1. Ship locations during EN216 CTD casts. (Table 5 - Cronin, 1990)

Cast #	Start of Cast lat	Start of Cast long	End of Downcast lat	End of Downcast long	End of Upcast lat	End of Upcast long
1	34.8333	73.1667	34.8405	73.1548	34.8533	73.1417
2	35.0103	73.3818			35.0262	73.3452
3	35.1742	73.6057	35.1653	73.5982	35.1493	73.5882
4	35.3330	73.8483			35.3398	73.8138
5	35.3858	73.9635			35.4208	73.9248
6	35.4847	74.0830				
7	35.5558	74.1028	35.5685	74.0790	35.5912	74.0400
8	35.6018	74.2438	35.6533	74.1465		
9	35.6683	74.3618	35.6890	74.3268	35.7118	74.2840
10	35.7140	74.5030	35.7158	74.5010	35.7063	74.5105
11	35.8500	74.5667				
12	35.9538	74.7190	35.9548	74.7180	35.9550	74.7148

Table 2. Geographical information for EN216 CTD section.

Cast #	Bottom Depth (m)	Distance from Previous Station (km)	Distance Drifted during Downcast (km)	Distance Drifted during Entire Cast (km)
1	4286.0	0	1.3413	3.1839
2	4021.0	27.7697		3.7722
3	3709.0	27.3057	1.1948	3.1847
4	3377.0	28.2202		3.2182
5	3180.0	11.9746		5.2336
6	2963.0	15.4165		
7	2869.0	8.1089	2.5734	6.9041
8	2730.0	13.7299	10.4897	
9	2365.0	12.9681	3.9057	8.5269
10	1893.0	13.7135	0.2721	1.0880
11	1613.0	16.1654		
12	1260.0	17.9201	0.1430	0.3966

Table 3. Bottle sample data. P_{adj}, T_{adj}, and S_{calc} are average values measured by the CTD during bottle sample stops. S_{bottle} is the salinity of the bottle sample measured via salinometer.

Cast #	P_{adj} (dbar)	T_{adj} (°C)	S_{calc} (PSU)	S_{bottle} (PSU)
1	4296.9	2.2034	34.8932	34.894
	4296.9	2.2034	34.8932	34.893
	2286.3	3.6542	34.9782	34.977
	2286.3	3.6542	34.9782	34.987
	1365.0	4.6838	35.0134	35.015
	1365.0	4.6838	35.0134	35.014
	0005.2	18.0517	36.6544	36.516
	0005.2	18.0517	36.6544	36.512
2	3293.6	2.5584	34.9269	34.924
	3293.6	2.5584	34.9269	34.924
	2298.2	3.6548	34.9816	34.979
	2298.2	3.6548	34.9816	34.979
	1369.2	4.6624	35.0166	35.012
	1369.2	4.6624	35.0166	35.015
	0383.0	18.0488	36.5123	36.511
	0383.0	18.0488	36.5123	36.516
3	3313.4	2.4996	34.9234	34.921
	3313.4	2.4996	34.9234	34.900
	2275.8	3.6261	34.9821	34.984
	2240.3	3.6768	34.9866	34.982
	1335.5	4.7328	35.0370	35.074
	1335.5	4.7328	35.0370	35.075
	0328.5	18.1272	36.5126	36.512
	0328.5	18.1272	36.5126	36.510
4	3258.6	2.4764	34.9227	34.923
	3258.6	2.4764	34.9227	34.922
	2177.7	3.6654	34.9899	34.985
	2177.7	3.6654	34.9899	34.989
	1252.3	4.5168	35.0033	34.994
	1252.3	4.5168	35.0033	34.996
	0345.9	18.0570	36.4997	36.507
	0345.9	18.0570	36.4997	36.505
5	3184.7	2.5412	34.9267	34.984
	3184.7	2.5412	34.9267	34.924
	2171.9	3.6491	34.9829	34.987
	2171.9	3.6491	34.9829	34.981
	1194.5	4.6307	35.0151	35.009
	1194.5	4.6307	35.0151	35.006
	0339.1	18.0996	36.5045	36.499
	0339.1	18.0996	36.5045	36.535
6	2915.9	2.7657	34.9378	34.932
	2915.9	2.7657	34.9378	34.936
	2005.8	3.6399	34.9740	34.971
	2005.8	3.6399	34.9740	34.973
	1037.6	4.6160	35.0089	35.010
	1037.6	4.6160	35.0089	35.005
	0289.2	18.1449	36.5122	36.507
	0289.2	18.1449	36.5122	36.511
7	2863.4	2.8060	34.9405	34.934
	2863.4	2.8060	34.9405	34.939
	1974.2	3.6500	34.9738	34.969
	1974.2	3.6500	34.9738	34.967
	1051.8	4.6126	35.0218	35.022
	1051.8	4.6126	35.0218	35.019
	0270.2	18.0970	36.5107	36.552
	0270.2	18.0970	36.5107	no data
8	2678.8	2.8755	34.9448	34.950
	2678.8	2.8755	34.9448	34.956
	1960.8	3.6309	34.9746	34.977
	1960.8	3.6309	34.9746	34.972
	0863.7	4.6412	34.9887	34.981
	0863.7	4.6412	34.9887	34.986
	0224.0	18.1845	36.5175	36.510
	0224.0	18.1845	36.5175	36.529
9	1884.6	3.6018	34.9739	36.297 *
	1884.6	3.6018	34.9739	34.970
	0751.8	4.5909	34.9907	34.994
	0751.8	4.5909	34.9907	34.905
	0471.9	5.8455	35.0095	35.017
	0471.9	5.8455	35.0095	35.004
	0144.7	18.5359	36.4611	36.496
	0144.7	18.5359	36.4611	36.437
10	1886.3	3.5598	34.9739	34.968
	1886.3	3.5598	34.9739	34.987
	0691.3	4.6197	34.9916	34.985
	0691.3	4.6197	34.9916	34.989
	0400.0	6.3383	35.0095	35.006
	0400.0	6.3383	35.0095	35.004
	0096.7	16.4789	35.5134	35.629
	0096.7	16.4789	35.5134	35.580
11	1603.8	3.7654	34.9709	no data
	1603.8	3.7654	34.9709	34.972
	0761.6	4.5894	34.9918	34.993
	0761.6	4.5894	34.9918	35.001
	0418.0	6.1249	35.0070	35.007
	0418.0	6.1249	35.0070	35.000
	0062.1	11.5950	33.6374	33.611
	0062.1	11.5950	33.6374	33.610
12	1219.3	4.0255	34.9734	34.978
	1219.3	4.0255	34.9734	34.966
	0785.7	4.5988	34.9929	34.983
	0785.7	4.5988	34.9929	34.982
	0438.6	6.1190	34.9953	34.996
	0438.6	6.1190	34.9953	34.990
	0151.8	12.1521	35.4576	35.448
	0151.8	12.1521	35.4576	35.463

* data line discarded as outlier

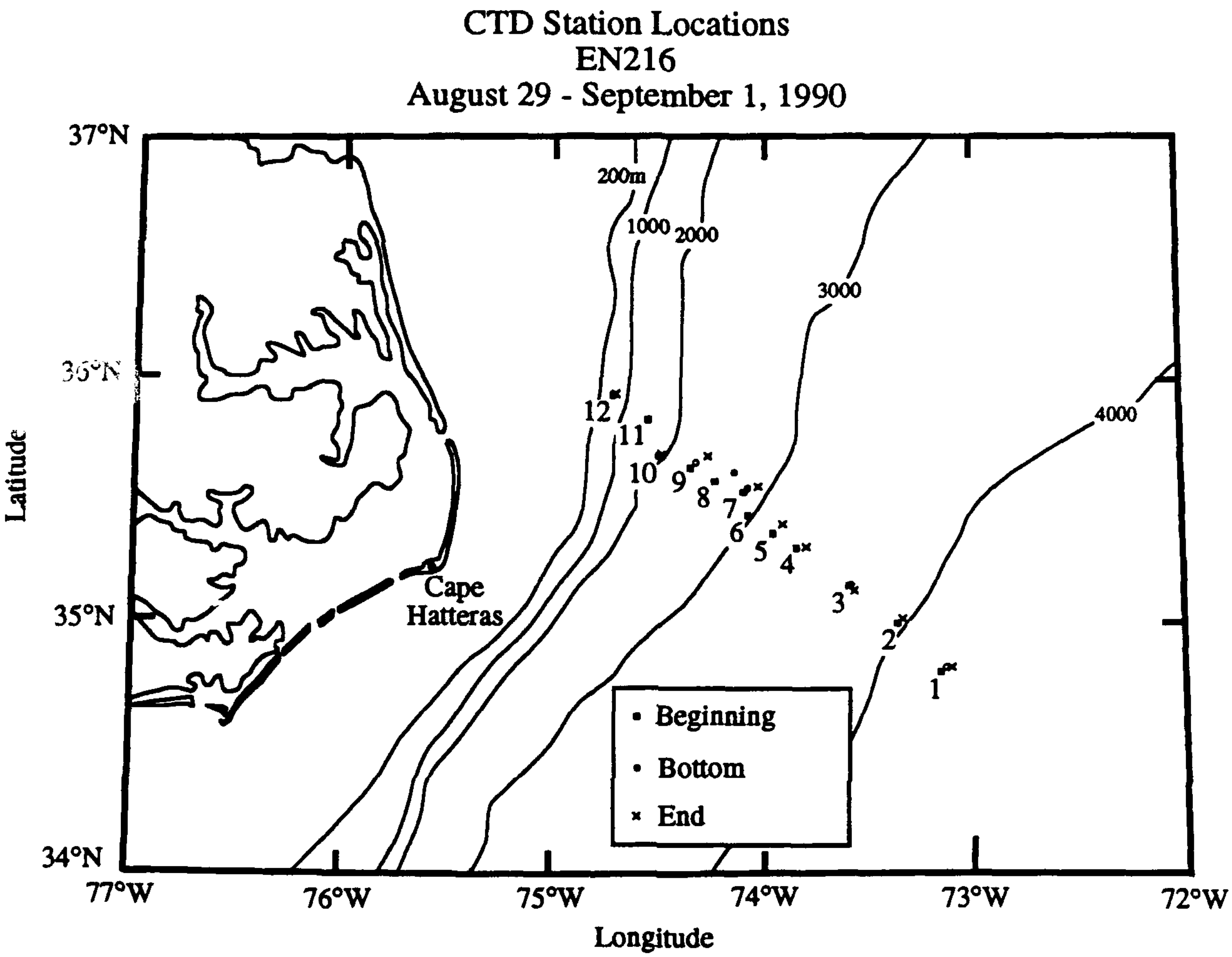

Figure 1. Location of CTD casts from section taken on cruise EN216, from August 29 to September 1, 1990. Shown are ship locations at (1) the start of each downcast (solid squares), (2) the end of each downcast (open circles), and (3) the end of each upcast (x marks). Stations were occupied in order from Station 1 to Station 12.

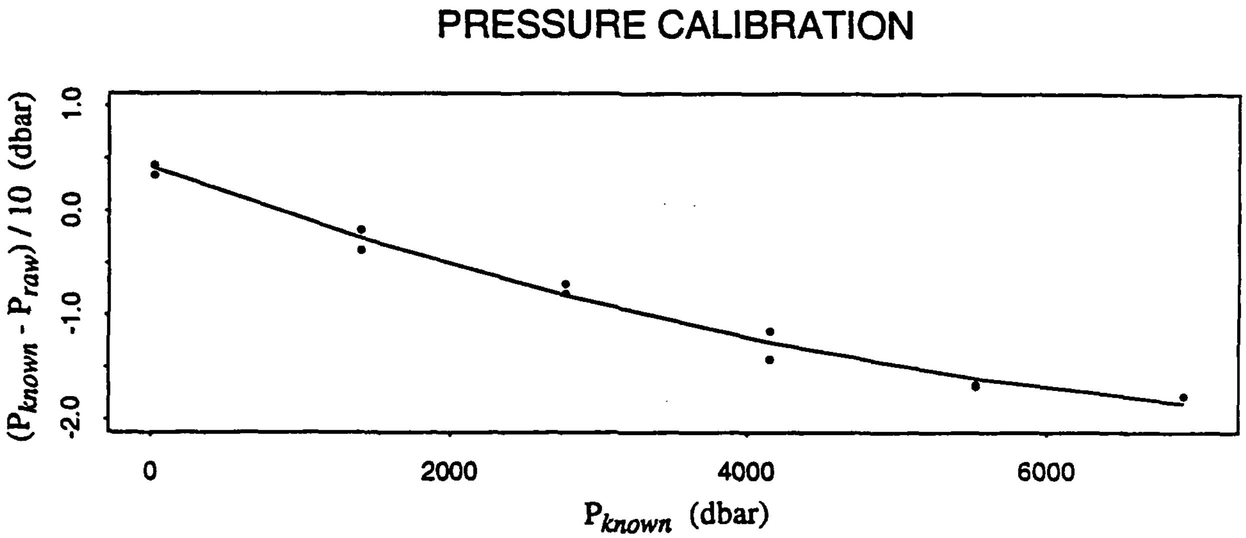

Figure 2. Pressure calibration data. Shown is the amount the pressure sensor drifted over the 5 months between the pre-cruise calibration and the post-cruise calibration ($P_{delta} = P_{known} - P_{raw}$) divided by ten (cruise occurred only one tenth of the way through that 5 months) as a function of pressure. The solid line shows the 2nd order polynomial fit to the drift.

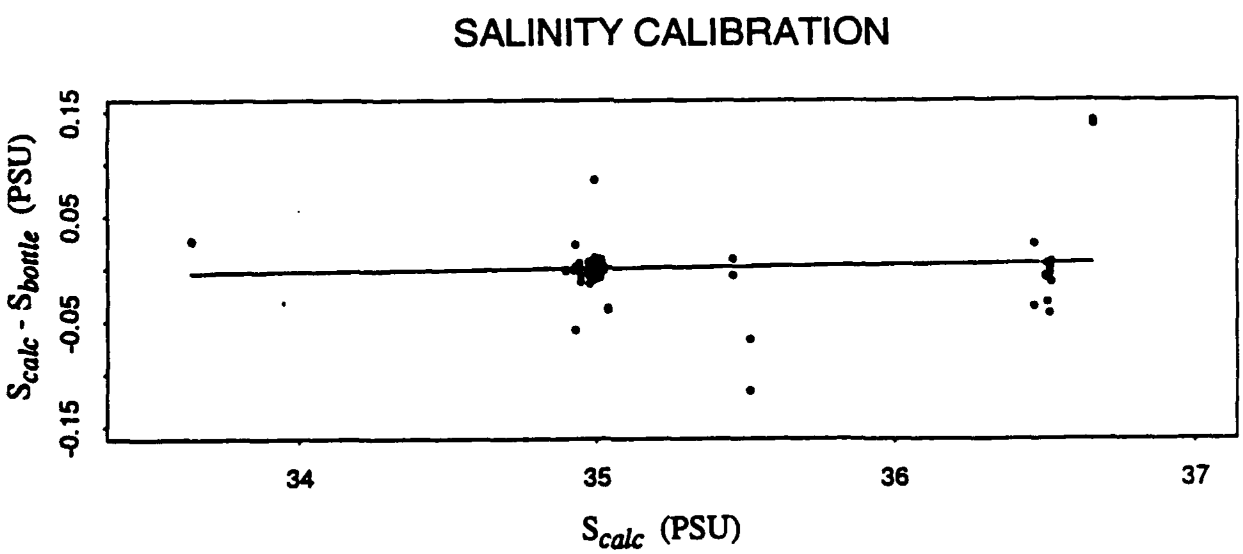

Figure 3. Salinity calibration data. Shown are differences between the average salinities measured by the CTD during bottle stops and the salinities from the bottle samples measured with a salinometer, plotted as a function of salinity. The solid line shows the 1st order polynomial fit to the data.

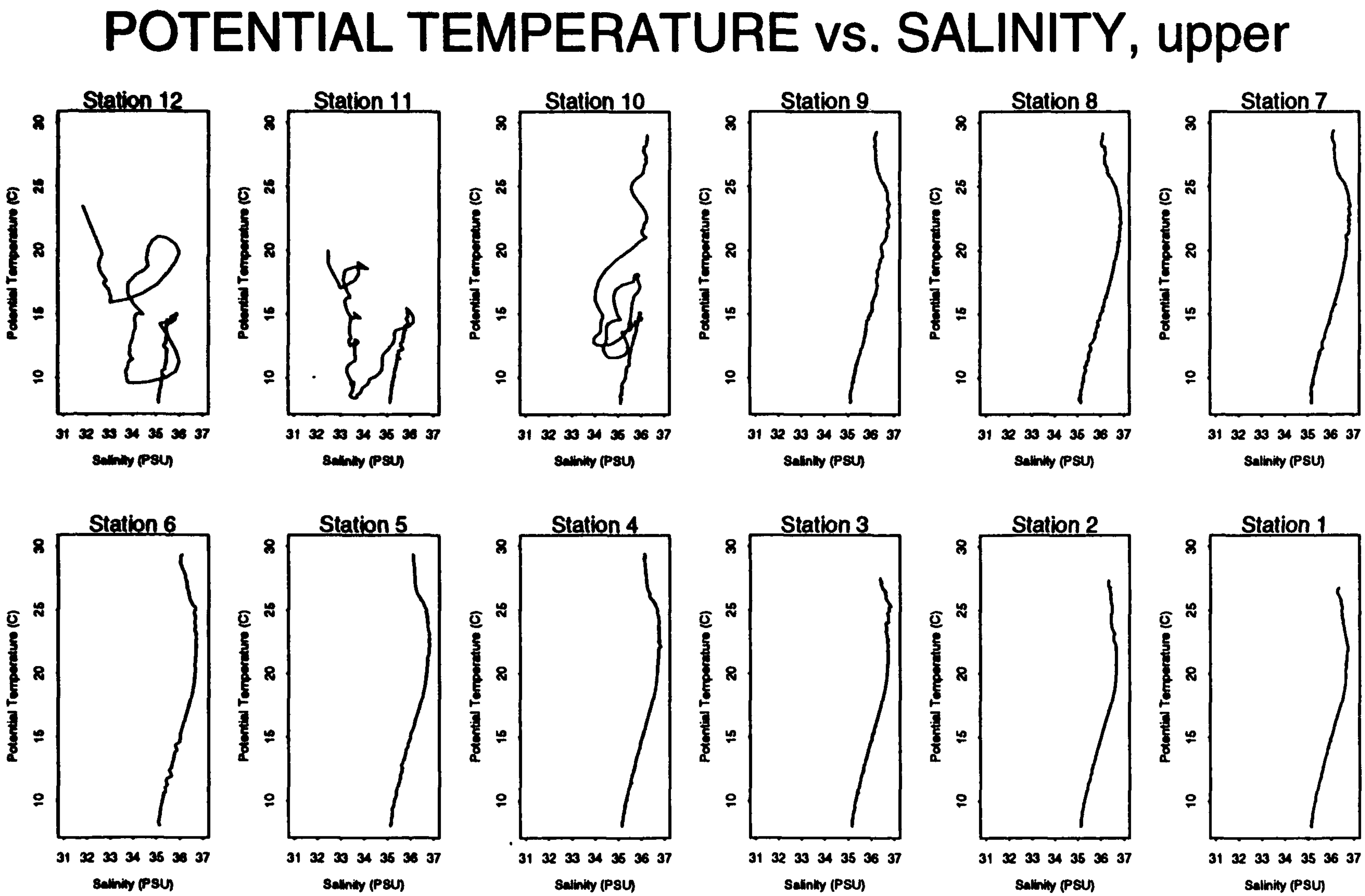

Figure 4. Potential Temperature (θ, in ^{o}C) vs. Salinity (in PSU) for the upper water column ($\theta > 8\ ^{o}C$). Shown are CTD casts 12 through 1 in onshore to offshore order. Theta is referenced to the P = 0 surface.

POTENTIAL TEMPERATURE vs. SALINITY, lower

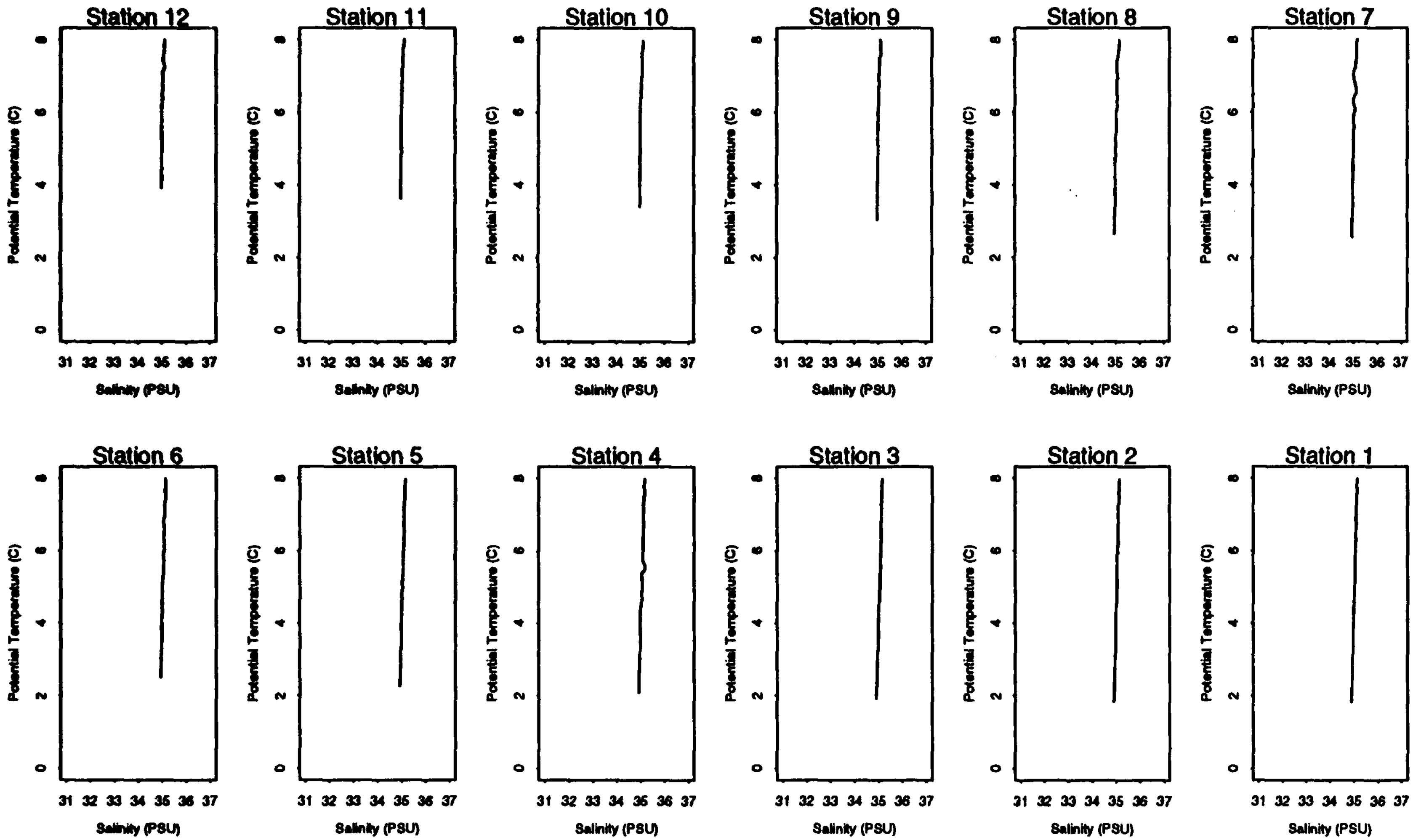

Figure 5. Potential Temperature (θ, in ^{o}C) vs. Salinity (in PSU) for the lower water column ($\theta < 8\ ^{o}C$). Shown are CTD casts 12 through 1 in onshore to offshore order. θ is referenced to the $P = 0$ surface.

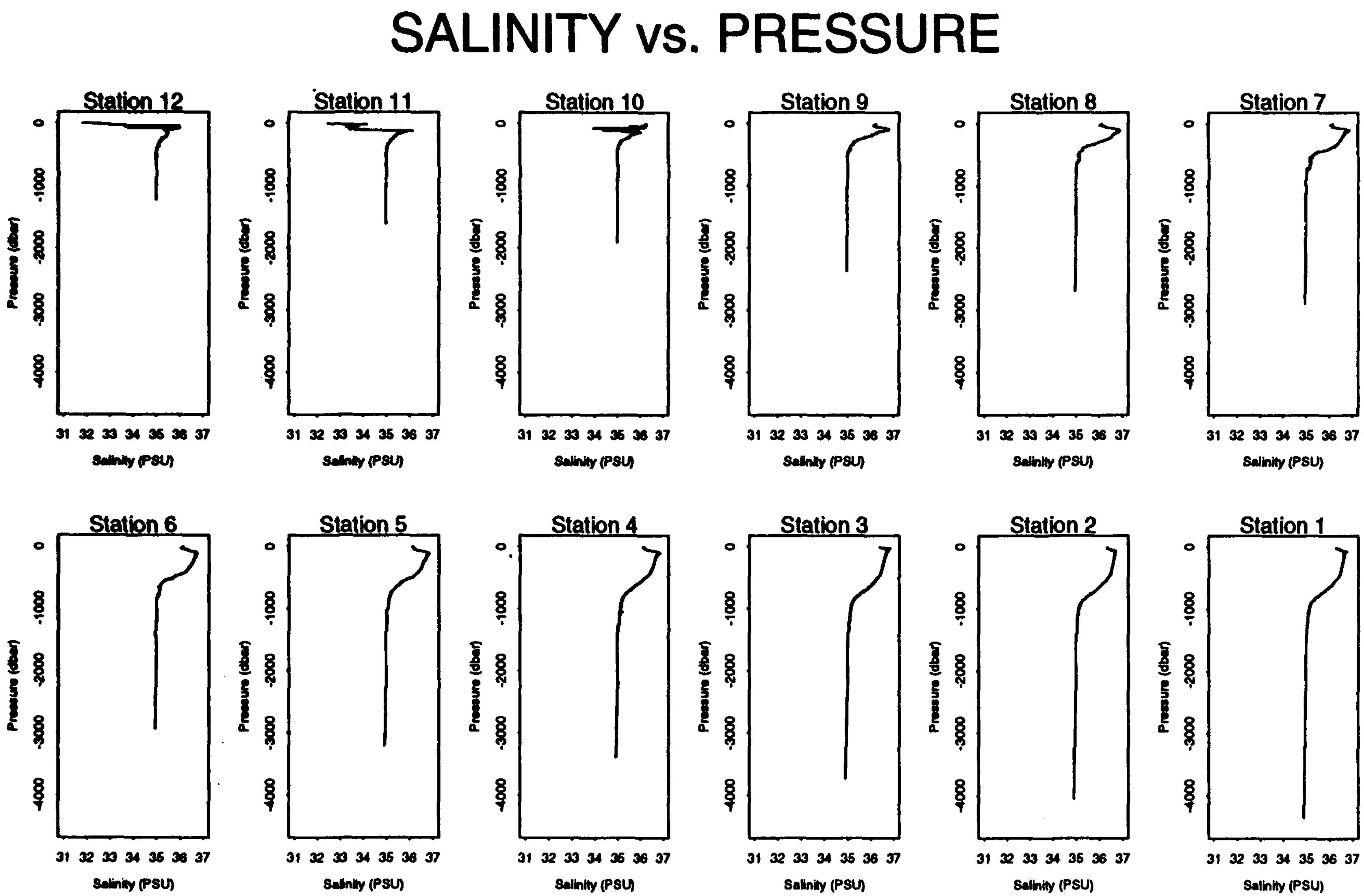

Figure 6. Salinity profiles. Shown is Salinity (in PSU) as a function of Pressure (in dbar) for casts 12 through 1 in onshore to offshore order.

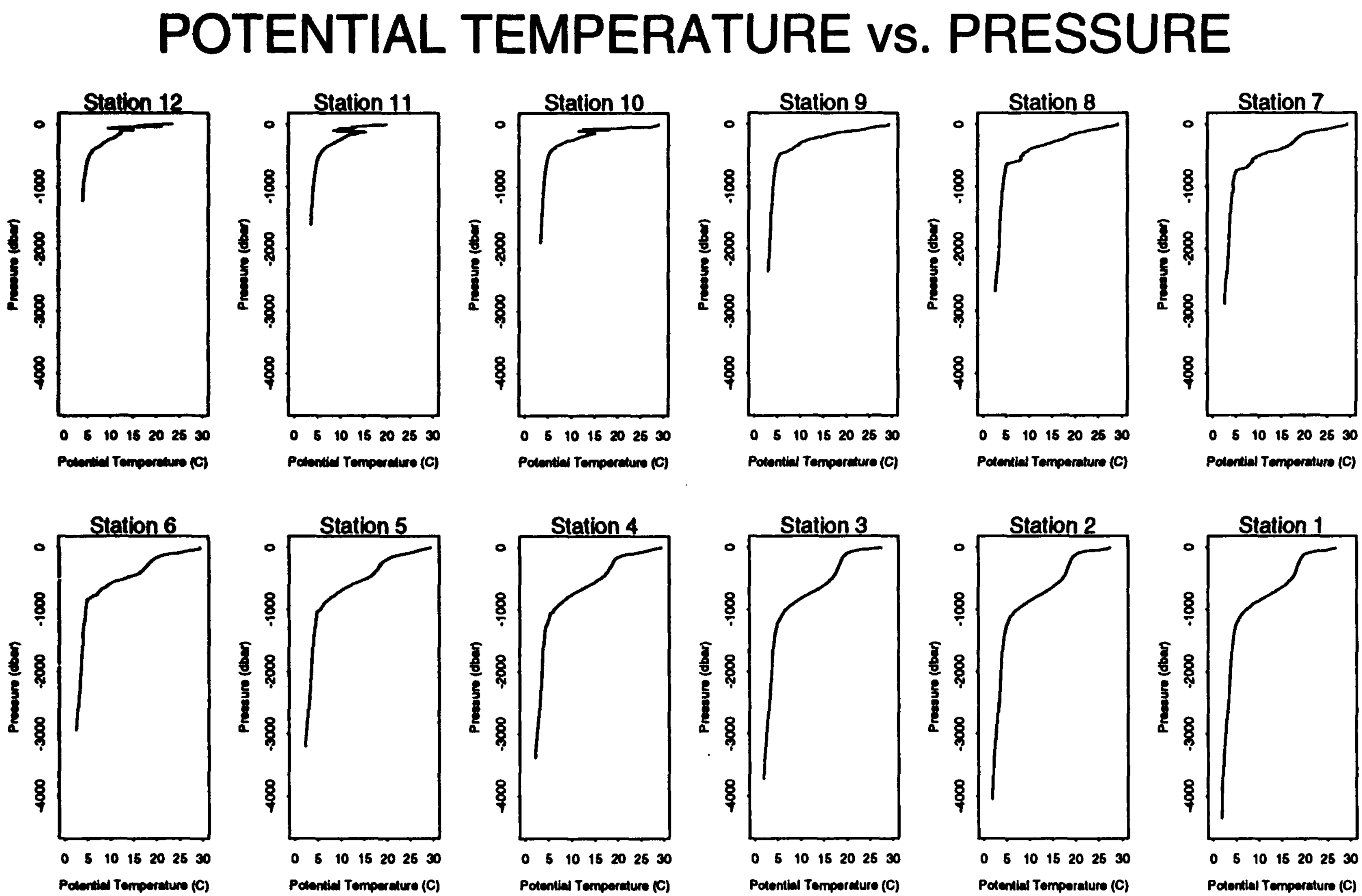

Figure 7. Potential Temperature profiles. Shown is Potential Temperature (θ, in ^{o}C) as a function of Pressure (in dbar) for casts 12 through 1 in onshore to offshore order. θ is referenced to the P = 0 surface.

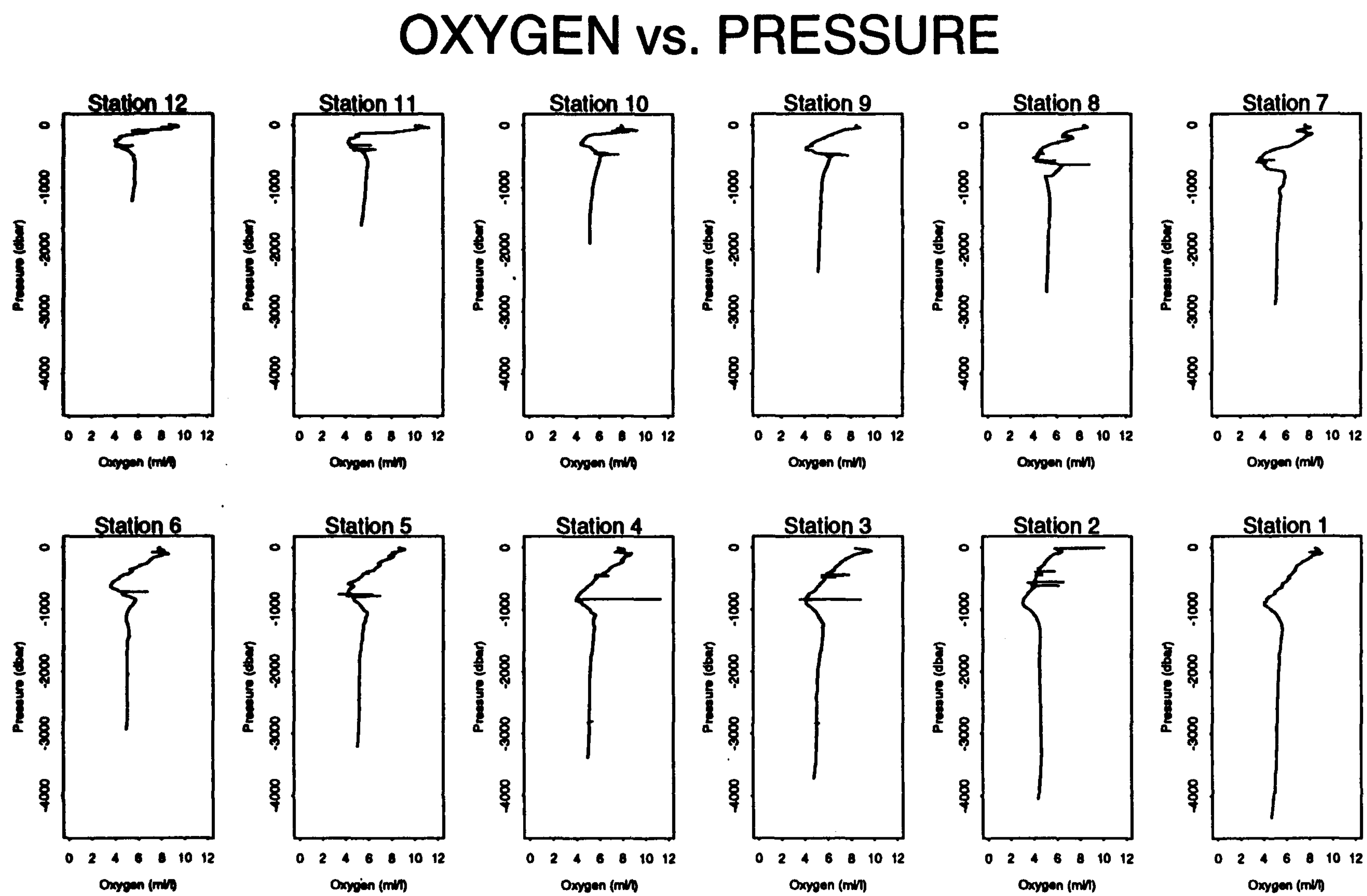

Figure 8. Oxygen profiles. Shown is Oxygen (in ml/l) as a function of Pressure (in dbar) for casts 12 through 1 in onshore to offshore order.

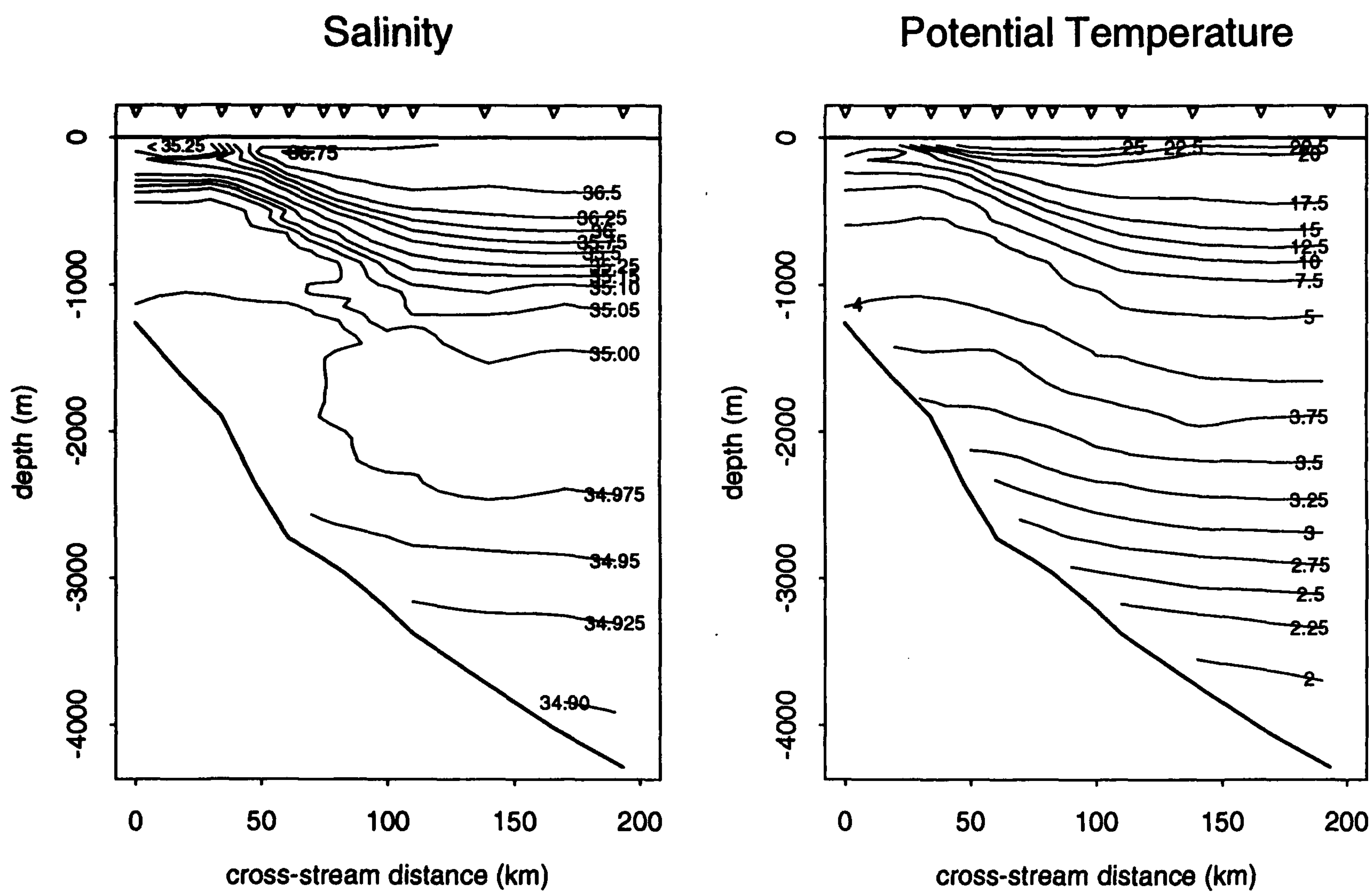

Figure 9. Vertical sections of (a) Salinity (in PSU) and (b) Potential Temperature (in ^{0}C), referenced to the P = 0 surface. Station locations (Stations 12 through 1, left to right) are shown as small triangles along the tops of the sections.

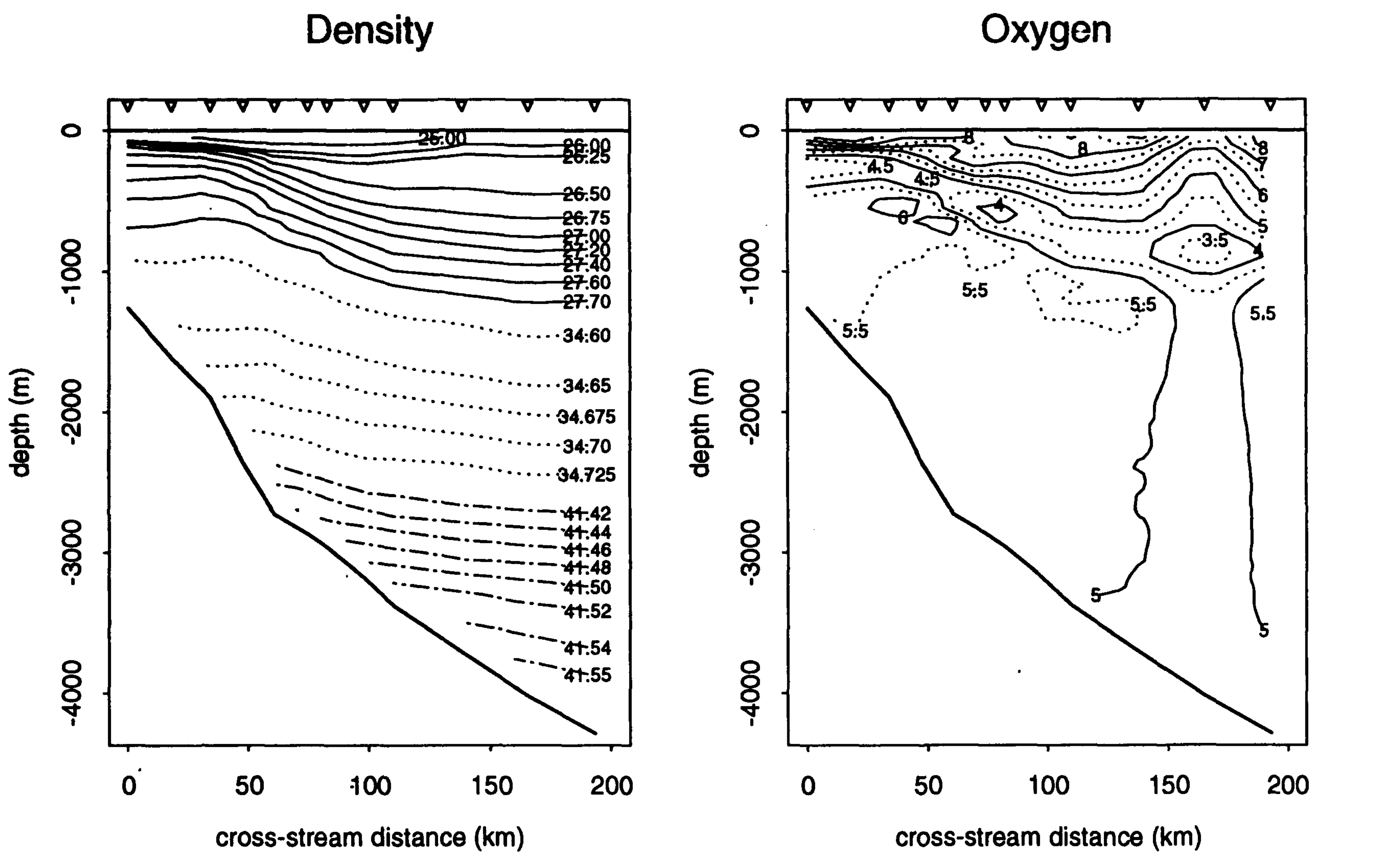

Figure 10. Vertical sections of (a) Density (σ_0, $\sigma_{1.5}$, and $\sigma_{3.0}$ in sigma units), and (b) Oxygen (in ml/l). In the density section, solid lines are σ_0, dotted lines are $\sigma_{1.5}$, and dot-dashed lines are $\sigma_{3.0}$. Station locations (Stations 12 through 1, left to right) are shown as small triangles along the tops of the sections.

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A CTD section was taken across the Gulf Stream during late August, 1990, approximately 100 km downstream from Cape Hatteras. The work was done from the R/V Endeavor during the third leg of cruise EN216, which was part of the SYNoptic Ocean Prediction (SYNOP) program. The section consisted of 12 stations located along a line from 34°50'N, 73°10'W to 35°57.23'N, 74°43.14'W, spaced 8 to 30 km apart. The Seabird Sealogger utilized was equipped with conductivity, temperature, pressure, and oxygen sensors. Nominal drop speed was 0.5 – 1.0 m/s, with a sampling rate of 1 Hz. This report discusses the acquistion and processing of the CTD data obtained along this section. In addition, plots of potential temperature vs. salinity, salinity vs. pressure,potential temperature vs. pressure, and oxygen vs. pressure are shown for each station. Vertical sections of salinity, potential temperature, density, and oxygen are also presented.

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